Journal of Southeast University (English Edition) Vol. 31, No. 3, pp. 412 -417 Sept. 2015 ISSN 1003—7985

Influence analysis of chevron alignment signs on drivers' speed choices at horizontal curves on highways

Wu Yiping[1] Zhao Xiaohua[1] Rong Jian[1] Ma Jianming[2]

([1]Beijing Key Laboratory of Traffic Engineering, Beijing University of Technology, Beijing 100124, China)
([2]Texas Department of Transportation, Austin, TX 78750-2636, USA)

Abstract: Using a driving simulator, the effects of Chinese chevrons on drivers' actual and perceived safe speeds at horizontal curves on two-lane rural highways are tested. Twelve horizontal curves with different roadway geometries are designed and used as the simulated scenarios. The results show that, regardless of the curve radius, chevrons at horizontal curves provide advance warning and speed control for vehicles on the nearside of chevrons. Besides, chevrons can be used as an addition to speed limit signs in preventing excessive speed at horizontal curves and, therefore, can contribute to a reduction in run-off-road crashes. Moreover, Chinese chevrons can also serve to provide an improved sense of safety while driving around sharp curves. These study results lay a foundation for setting Chinese chevrons more reasonably.

Key words: chevron alignment sign; driving simulator experiment; speed; horizontal curves

doi: 10.3969/j.issn.1003 -7985.2015.03.020

The chevron alignment sign is an important element of curve delineation devices, and it serves two main purposes. First, it allows for better visibility when approaching a curve and provides positive guidance while navigating through it. Secondly, properly spaced chevrons can be helpful in encouraging drivers to reduce their speed going into and through a curve[1].

Unlike in other countries, the chevron alignment sign in China is a vertical rectangle with a white arrow and border on a blue background; more detailed information about the chevron in China has been given in another paper by Wu et al[2]. Moreover, the effect of Chinese chevron alignment signs on driving behavior has rarely been studied in the past, and the guidance for setting chevrons is too vague, offering no clear and specific requirements for using chevrons under various traffic, roadway and environmental conditions[3-4]. Although the effectiveness of chevrons has been studied thoroughly in the US[5-7] and the guidelines for setting chevrons are also clearly stated in the Manual on Uniform Traffic Control Devices (MUTCD)[8], these study results and guidelines in the American MUTCD might not be directly transferrable to China due to the differing chevron design as well as the unique characteristics of the Chinese driving population. Therefore, the goals of this research sponsored by the Beijing Traffic Management Bureau was to thoroughly analyze the effects of Chinese chevron alignment signs on driving behavior and then develop a set of practical and optimal design criteria for implementing chevrons on Chinese highways.

As a pilot study, the effect of Chinese chevrons on drivers' eye movements, driving performance (steering, braking and releasing the accelerator), vehicle operations (speed and lateral placement) and stress in a given road condition has been analyzed[2, 9]. Additionally, chevrons' influence on driver stress in different horizontal curves was also discussed[10]. However, it is still unclear whether the geometric design features of horizontal curves play a role in determining the effects of chevrons on drivers' speed choice. Thus, in the current study, two important roadway geometric conditions of horizontal curves, curve radius and curve direction, were considered and controlled. This study was intended to lay a foundation for developing guidelines for implementing chevrons in different horizontal curves. In this paper, we discuss the effect of chevrons on drivers' speed (longitudinal control) in depth.

1 Experimental Design and Methods

1.1 Participants selection

36 healthy male drivers with a Chinese driver's license Type B, an age range of 20 to 34 years (average (Av) = 24.8, standard deviation (SD) = 3.66) and having 2 to 8 years (Av = 3.4, SD = 1.63) driving experience were recruited by announcement in this experiment. All participants provided written informed consent before joining in the experiment.

To explain briefly, the homogeneous sample of subjects selected intends to minimize bias attributable to sample heterogeneity, as the previous study demonstrated that

Received 2014-12-15.

Biographies: Wu Yiping (1990—), male, graduate; Zhao Xiaohua (corresponding author), female, doctor, professor, zhaoxiaohua@bjut.edu.cn.

Foundation item: The National Natural Science Foundation of China (No. 51108011).

Citation: Wu Yiping, Zhao Xiaohua, Rong Jian, et al. Influence analysis of chevron alignment signs on drivers' speed choices at horizontal curves on highways[J]. Journal of Southeast University (English Edition), 2015, 31(3): 412 -417. [doi: 10.3969/j.issn.1003 -7985.2015.03.020]

driving performance was mostly affected by age and gender[11], and female drivers were far fewer than male in China. Meanwhile, due to the high requirement for resources, it is common for simulator studies to have a small sample size[7, 11-12].

1.2 Experimental equipment

The driving simulator experiment was performed by using the fixed-base driving simulator in the Beijing Key Laboratory of Traffic Engineering, Beijing University of Technology. The hardware of this simulator consists of a renovated real car, computers, and video and audio equipment. The road scenario is projected onto three big screens, providing the driver with a 130° wide-angle field of view. This simulator records the actions of drivers in the vehicle and parameters that describe the vehicle operating conditions at a frequency of 30 times/s. The data of drivers' actions collected by this simulator primarily includes steering wheel angle, steering wheel velocity, throttle input, and brake pedal force; the data of vehicle operations includes longitudinal and lateral acceleration, longitudinal and lateral velocity, lateral lane position and distance traveled.

Moreover, the validation of this simulator has been testified in previous works. Until now, a total of 200 drivers who participated in previous driving simulator studies were used to evaluate the validation of this driving simulator through questionnaires. The average score in terms of an authentic sense of speed perception while driving in the simulator reached 7.7 (1—not real at all; 10—very real). Moreover, we also validated the effectiveness of the driving simulator for travel speed in curves paved with chevrons. Sifang Interchange of the Fourth Ring Road in Beijing was selected as the study site. The results indicate that the speed variation trend in the curves paved with chevrons was highly similar to the trend in the real road environment[13]. Thus, this driving simulator appears to be a valuable research tool for speed-related studies.

1.3 Experimental scenarios development

The road in the simulated scenario was a two-lane rural undivided highway with one lane in each direction, and each lane measuring 3.75 m in width. Both of the shoulders in each direction are 0.75 m. The two lanes are separated by a dot yellow line in straight segments and a solid yellow line in curves. In order to eliminate interference from confounding factors on the experimental data, the terrain surrounding all the sections is made flat and uniform, and there are no other vehicles present during the entire scenario. The scenario is simulated for daytime driving.

Horizontal curves in the simulated scenario are designed to combine chevron presence (with or without), curve radius (sharp, moderate, or flat) and curve direction (left or right). Thus, all participants experienced 12 different horizontal curves during the whole experiment. Fig. 1 displays some examples of the horizontal curves with the combination of these three factors. To limit the effects of previous curve geometry on the following curve, after our tests in the simulator, the simulated road was designed so that the two horizontal curves are separated by one straight section, and the length of the straight section is about 800 to 1 000 m.

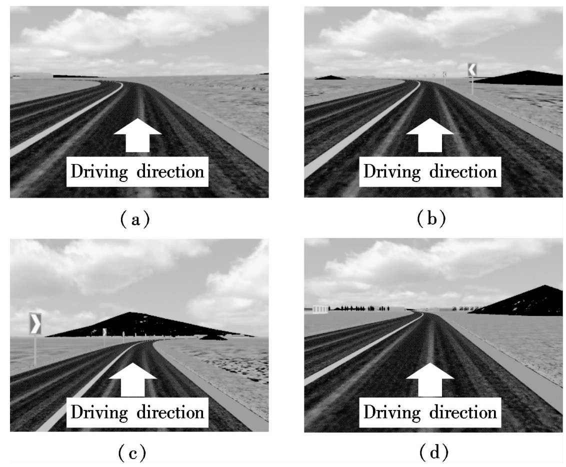

Fig. 1 Screen shot pictures of scenarios. (a) Left sharp curve without chevrons; (b) Left sharp curve with chevrons; (c) Right moderate curve with chevrons; (d) Left flat curve without chevrons

According to the Design Specification for Highway Alignment in China[14], the design speed of 60 km/h for a 125 m radius was set for the sharp curve in this experiment, and the design speeds of 80 km/h for a radius between 400 and 1 000 m were set for the moderate curve and the flat curve, respectively. There was no superelevation, spiral transitions or grade designed for each curve. The length of each curve was designed for the driving time lasting 5 s based on the design speed. Chevrons were placed evenly around the outside edge of the horizontal curves with a spacing of 12 m from the point of the curve to the point of the tangent.

To minimize the confounding influence of other traffic control devices on driver speed and to urge drivers to rely solely on chevrons when negotiating curves, advance warning signs and edge lines for both directions were omitted in the experiment. A speed limit sign of 80 km/h was placed at each tangent segment, which was 200 m away from the point of the tangent. Therefore, we could ensure that participants maintain their speed at a reasonable level, because too many run-off-road crashes caused by speeding will invalidate our experimental data.

1.4 Experimental procedure

The experiment included three parts: a test drive in the simulator, a before-drive questionnaire, and a main drive through the designed scenarios. During a drive in the simulator, each participant was asked to stay in the right lane only and maintain a comfortable, reasonable and safe speed according to the road conditions.

All participants took a test drive to become familiar with the simulator's steering and braking dynamics. Another purpose of the test drive was to allow participants to become familiar with the manipulating behavior needed on horizontal curves, especially on the sharp ones. The road used for the test drive was another rural highway with various horizontal curves but different from the road scenes used for the main drive. Throughout the test drive, no chevrons were used. The time for each participant's test drive was 3 to 5 min, depending on his driving speed.

Before the main drive, all participants were screened using a before-drive questionnaire to collect information about their age, profession and driving experience, to inquire if they had any health issues that would affect driving, and whether they were under the influence of drugs, stimulating food or alcoholic beverages.

For the main drive, each participant took about 10 min to complete the driving tasks in the simulator. During the entire experiment, the operator sat in the front passenger seat of the car to record the safe driving speed evaluated by participants. After passing through a horizontal curve and entering into the tangent section for a little while, the operator would remind participants to report which speed they evaluated to be safe for the curve just passed through. The process lasted about 5 s and no additional cognitive task influenced driving performance along curves after our repeated tests. It is worth noting that the speedometer was invisible to the subject during the experiment because Green et al.[15] found no effect of lane width or sight distance on the average speed when the speedometer was visible to drivers during their experiment.

2 Effects of Chevrons on Actual Speed

After removing the invalid data due to simulation sickness and anomalous values, the data from 30 samples was used in the following analysis. First, it was determined whether the starting situation for curves with chevrons and curves without chevrons was the same. We set a control point (CP) 400 m in advance of the point of curve. At the CP, any treatment for the curves was not present or visible. An analysis of variance with repeated measures (RANOVA) was used to determine whether there was a significant difference between the speed at the CP when chevrons were present and absent. The result revealed no statistically significant effect of chevron presence on driving speeds ($F_{(1,29)} = 1.869$, $p = 0.154$). Thus, the treatment order effect between curves with and without chevrons did not exist.

2.1 Average speed

The actual average speed used in this study was calculated from the point of curve to the point of tangent. The method of RANOVA was employed to examine the effect of chevrons on the mean driving speed. The results show a significant main effect of chevrons on the average speed ($F_{(1,29)} = 16.357$; $p < 0.001$), and the average speed when chevrons were present (Av = 66.86 km/h; SD = 1.20) was lower than that when chevrons were absent (Av = 69.89 km/h; SD = 1.07).

The effect of roadway geometries on average driving speed was also examined. In this case, we found a significant main effect of curve radius on average speed ($F_{(2,58)} = 114.083$; $p < 0.001$). A contrast analysis revealed that the average speed was positively correlated with the curve radius: the average speed increased from 55.42 km/h on the sharp curve to 70.92 km/h on the moderate curve, and to 79.42 km/h on the flat curve. No main effect was found for the curve direction factor ($F_{(1,29)} = 0.209$; $p = 0.648$).

The RANOVA also revealed a significant interaction between chevron presence and curve direction ($F_{(1,29)} = 6.644$; $p = 0.011$), as shown in Fig. 2(a). On leftward curves, the average speed was lower when chevrons were present than that when chevrons were absent; when driving in rightward curves, the effect of chevrons was minimal and the average speed remained relatively constant. No significant interaction was found between chevron presence and curve radius ($F_{(2,58)} = 0.615$; $p = 0.542$), as presented in Fig. 2(b). On one hand, drivers are more likely to increase their speed as the radius becomes larger, regardless of whether chevrons are present. On the other hand, when chevrons are present, the actual average speed is always lower than that without chevrons.

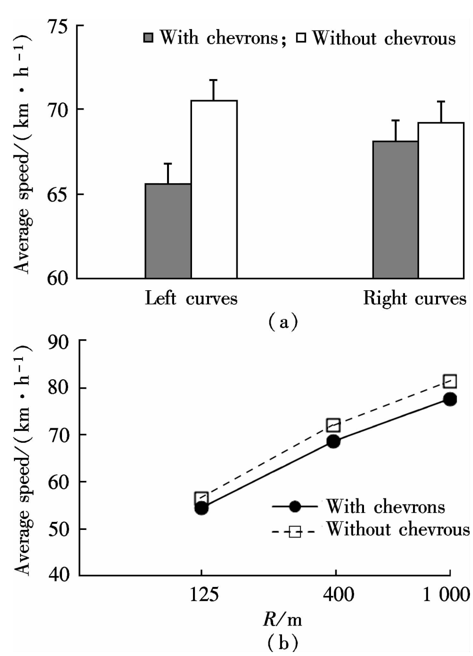

Fig. 2 Effects of chevron presence and roadway geometries on actual average speed. (a) The effect of chevron presence and curve direction; (b) The effect of chevron presence and curve radius

Therefore, these results indicate that chevron alignment signs did encourage drivers to reduce their speeds at left curves. Besides, no main effects of curve direction were found for the actual average speeds, but the curve direction did affect the function of chevrons on reducing actual speeds. In the current study, chevrons were always placed outside of horizontal curves and participants were required to remain in the right lane during the entire driving simulation. Thus, when driving in left curves, chevrons were near drivers and participants drove at a lower speed in the presence of chevrons than that without chevrons; while driving in right curves, chevrons were farther away from drivers and the speeds did not seem to be sensitive to the presence of chevrons. These findings illustrate that chevrons were more effective for driving in the lane near the outside of curves, and thus, for highway safety engineering, optimal placement of chevrons needs to be further explored in future research.

2.2 Speeds at key points

Since the effect of chevrons on driving speeds may be different at different locations along the curves, the average speed at four key points (see Fig. 3(a)) for each curve, combined with the factor of chevron presence, was calculated, as presented in Fig. 3(b). The point of curve (PC) and the point of tangent (PT) are the beginning and ending points of the curve, respectively. The approach of curve (AC) was a point placed 300 m in advance of PC on the straight segment. MC is the middle of curve. As shown in Fig. 3(b), the average speed at every key point when chevrons were present was always lower than that when chevrons were absent. In addition, the biggest difference in speeds between curves with and without chevrons was reached at the MC.

RANOVA was used to examine the main effect of chevron presence, the interaction between chevron presence and curve radius, and the interaction between chevron presence and curve direction. As presented in Tab. 1, the results reveal a significant main effect of chevron presence on driving speeds at the key points of AC, MC, and PT, respectively. However, no main effect of chevron presence was found for the average speed at the PC.

Results of RANOVA also show a significant interaction between chevron presence and curve direction at the MC. Similar to the results of the average speed, the driving speed at the MC was significantly lower in the presence of chevrons for left curves but remained about the same for right curves. No other interaction was found for the remaining key points.

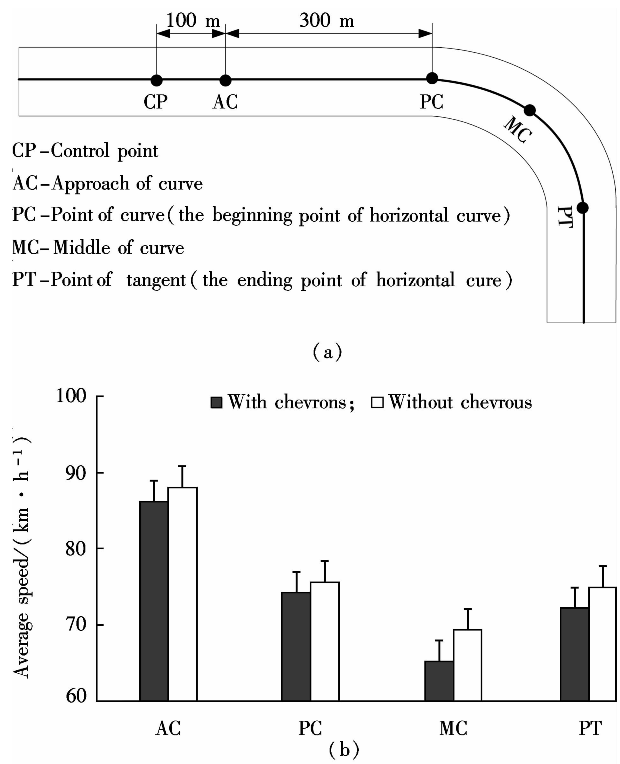

Fig. 3 Effects of chevron presence on actual average speed at four key points of horizontal curves. (a) The key points on the horizontal curves (not to scale); (b) The actual average speed at four key points on horizontal curves

Tab. 1 Results of RANOVA for driving speeds at each key point of curves

Key point	Main effects of chevrons		Interactions between chevrons and cure radius		Interactions between chevrons and cure direction	
	$F_{(1,29)}$	p	$F_{(2,58)}$	p	$F_{(1,29)}$	p
AC	6.000	0.015*	0.202	0.817	0.598	0.440
PC	1.969	0.162	1.714	0.183	1.966	0.163
MC	22.769	0.001*	0.132	0.876	6.579	0.011*
PT	16.342	0.001*	2.673	0.074	6.023	0.879

* The significance level is 0.05.

2.3 The 85th percentile speed

The 85th percentile speed is commonly used as the reference for establishing roadway speed limits on highways in China[16]. In this case, we found that the 85th percentile speed was 75.24 km/h when chevrons were absent, and it dropped to 72.42 km/h when chevrons were present. With the curve radius factor, it followed the same trend of the average speed: the 85th percentile speed increased from 61.91 km/h at the sharp curve to 76.34 km/h at the moderate curve, and to 83.24 km/h at the flat curve. The 85th percentile speed was 73.22 km/h in left curves and 74.44 km/h in right curves.

In addition, similar to the results of the average speed analysis, the 85th percentile speed was lower when driving in left curves with chevrons than in left curves without chevrons; the effect of chevrons on right side curves is negligible. Besides, regardless of whether chevrons were present or not, the 85th percentile speed was the highest when driving around flat curves, medium in moderate curves, and the lowest in sharp curves. When chevrons were present, the 85th percentile speed was always lower than that without chevrons. As a result, chevron alignment signs may help reduce run-off-road crashes since drivers' excessive speed is the primary reason for such crashes on horizontal curves.

3 Effects of Chevrons on Perceived Safe Speed

RANOVA was also applied to reveal the influence of chevron alignment signs on drivers' perceived safe speed. However, in contrast to the results of actual speeds, no significant main effect was found for the chevron presence factor ($F_{(1,29)}=0.210$; $p=0.647$), and the average perceived speeds in curves with and without chevrons are 55.31 and 55.59 m/h, respectively. There was a significant main effect for curve radius factor ($F_{(2,58)}=157.363$; $p<0.001$), and the average perceived safe speed increased from 41.25 km/h with the sharp curve to 56.31 km/h with the moderate curve, and to 68.79 m/h with the flat curve. No significant main effect of curve direction factor was found ($F_{(1,29)}=1.705$; $p=0.193$).

In addition, no significant interaction effect on perceived safe speed was found between chevron presence and curve direction ($F_{(1,29)}=1.705$; $p=0.193$), as shown in Fig. 4(a). For both left and right curves, the average perceived safe speed stays relatively constant whether chevrons are present or not. However, the RANOVA revealed a significant interaction between chevron presence and curve radius on perceived safe speed ($F_{(2,58)}=6.551$; $p=0.002$), as presented in Fig. 4(b). Consistent with the actual speed results, drivers increased their perceived safe speed as the radius became larger, regardless of the presence of chevrons. Different from the actual speed results, drivers' perceived safe speed with the presence of chevrons is lower than that when chevrons were absent in flat curves, but almost identical in moderate curves and even higher in sharp curves.

Hence, chevrons did not seem to bring a reduction in perceived safe speeds for either right or left curves. However, chevrons might have an opposite impact on drivers' perceived safe speed when combined with different curve radii. In sharp curves, it is difficult for participants to know the exact alignment of the curve without an additional topological reference. As chevrons define the direction and sharpness of the curve and provide positive guidance while negotiating the curve, the chevron sign might enhance a driver's sense of safety; the driver might therefore perceive a higher safe speed in the presence of chevrons. In contrast, drivers' perceived safe speeds did not seem to be sensitive to the presence of chevrons for flat curves because drivers can more easily figure out the roadway alignment for flat curves. Another explanation for the effect of chevrons on drivers' perceived safe speeds is that due to a lack of guidelines, chevrons have been installed at horizontal curves regardless of their sharpness. In this situation, chevrons fail to convey to drivers the information about the sharpness of the curves. Therefore, chevrons provided a false sense of safety to drivers, which results in a greater difference in drivers' perceived safe speeds (with chevrons vs. without chevrons) for sharp curves.

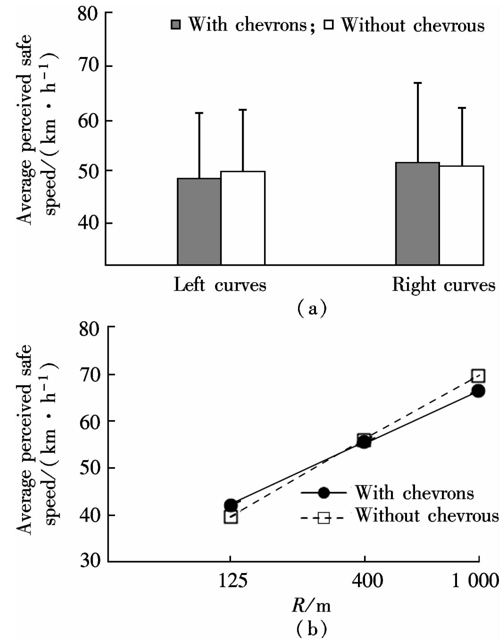

Fig. 4 Effects of chevron presence and roadway geometries on perceived safe speed. (a) The effect of chevron presence and curve direction; (b) The effect of chevron presence and curve radius

4 Conclusions

Based on a driving simulator experiment, the main contribution of this study is the combined effects of the chevron presence factor and curve geometry feature on drivers' actual speed and perceived safe speed. More detailed findings are described as below:

1) A significant main effect of chevrons on actual average speed was found; the function of chevrons on speed reduction was not significantly affected by curve radius, but it was considerably affected by curve direction. Additionally, the speed reduction caused by chevrons is always present at the approach of curve, the middle of curve and the point of tangent. Hence, regardless of the curve radius, placing chevrons close to the driving direction at horizontal curves can help to reduce the speeds of drivers approaching and navigating through curves.

2) We also found a significant reduction of the 85th percentile speeds caused by the chevrons, which suggests that chevron alignment signs appear to be a good addition to

other warning signs (e. g., one-direction large horizontal arrow signs) in preventing excessive speed on horizontal curves; they, therefore, can contribute to a reduction in run-off-road crashes when driving in the lane near the outside of curves.

3) Chevrons made drivers evaluate a higher safe speed for sharp curves compared with the absence of chevrons. Chinese chevrons can serve to enhance drivers' sense of safety while driving in sharp curves.

References

[1] Srinivasan R, Persaud B, Eccles K A, et al. Safety evaluation of improved curve delineation with signing enhancements [C/D]//*The 89th Annual Meeting of Transportation Research Board*. Washington DC, USA, 2010.

[2] Wu Y, Zhao X, Rong J, et al. Effects of chevron alignment signs on driver eye movements, driving performance, and stress [J]. *Transportation Research Record*, 2013, **2365**: 10 − 16.

[3] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ), Standardization Administration of the People's Republic of China (SAC). GB 5768. 2—2009 road traffic signs and markings-part 2: road traffic signs [S]. Beijing: China Standard Publishing House, 2009. (in Chinese)

[4] Huang J. The study on the placing of chevron alignment sign on high level road in mountainous areas [D]. Fuzhou: Fujian Agriculture and Forestry University, 2004. (in Chinese)

[5] Zador P, Stein H S, Wright P, et al. Effects of chevrons, post-mounted delineators, and raised pavement markers on driver behavior at roadway curves [J]. *Transportation Research Record*, 1987, **1114**: 36 − 44.

[6] Rose E R, Carlson P J. Spacing chevrons on horizontal curves [J]. *Transportation Research Record*, 2005, **1918**: 84 − 91.

[7] Van Der Horst R, De Ridder S. Influence of roadside infrastructure on driving behavior: driving simulator study [J]. *Transportation Research Record*, 2007, **2018**: 36 − 44.

[8] Federal Highway Administration. Manual on uniform traffic control devices for streets and highways [R]. Washington DC, USA: United States Department of Transportation, 2009.

[9] Wu Y, Zhao X, Rong J, et al. The effect of chevron alignment signs on driver performance [J]. *Journal of Beijing Institute of Technology*, 2012, **21**(S2): 201 − 204.

[10] Zhao X, Chi J, Wu Y, et al. Impact of chevron alignment sign on driver stress on horizontal curves: a simulator study [C]//*Proceedings of the 14th COTA International Conference of Transportation Professionals*. Changsha, China, 2014: 2494 − 2505.

[11] Calvi A, Benedetto A, De Blasiis M R. A driving simulator study of driver performance on deceleration lanes [J]. *Accident Analysis and Prevention*, 2012(45): 195 − 203.

[12] Ben-Bassat T, Shinar D. Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior [J]. *Accident Analysis and Prevention*, 2011(43): 2142 − 2152.

[13] Ding H, Zhao X, Rong J. Experimental research on the validation of the driving simulator in Beijing University of Technology [R]. Beijing: College of Metropolitan Transportation, Beijing University of Technology, 2014. (in Chinese)

[14] Ministry of Transport of the People's Republic of China. JTG D20—2006 design specification for highway alignment [S]. Beijing: China Communications Press, 2006. (in Chinese)

[15] Green P, Lin B, Bagian T. Driver workload as a function of road geometry: a pilot experiment [R]. Michigan, USA: Transportation Research Institute of University of Michigan, 1993.

[16] Xu J, Chen X. *Fundamentals of traffic engineering* [M]. Beijing: China Communications Press, 2008: 39 − 40. (in Chinese)

公路平曲线处线形诱导标对驾驶员速度选择的影响分析

伍毅平[1]　赵晓华[1]　荣　建[1]　马建明[2]

([1] 北京工业大学北京市交通工程重点实验室,北京 100124)

([2]Texas Department of Transportation, Austin, TX 78750-2636, USA)

摘要:利用驾驶模拟器,测试了我国线形诱导标在双车道公路平曲线上对驾驶员实际和感知安全速度的影响. 设计和使用 12 种具有不同道路几何条件的平曲线作为模拟场景. 结果表明,不受曲线半径影响,对行驶方向靠近线形诱导标的车辆,平曲线处的诱导标具有提前预警和速度控制的作用. 除此,线形诱导标可以辅助限速标志预防车辆在平曲线处超速行驶,进而有助于减少弯道处车辆冲出道路的事故. 此外,我国的线形诱导标可以增强急弯处行驶的安全感. 研究结果为更加规范合理设置我国的线形诱导标奠定基础.

关键词:线形诱导标;驾驶模拟实验;速度;平曲线

中图分类号:U491.25